THE BUMBLING BUS (A)

This case history describes a bus and automobile accident on a snowy day with gusty winds. Analysis of the situation involves rigid body dynamics with some fluid mechanics relating to drag forces on the bus due to winds.

Prepared by C. O. Smith. Published with support from the sponsors of the ASEE-Stanford Engineering Case Program:

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29 June 1972

Dr. C. O. S.
1530 Maple Drive
Detroit, Michigan 48221

Re: James Wright -vs- DSR
Earl Maschke -vs- DSR

Dear Dr. S.:

I am herewith enclosing a copy of the report of Mr. H concerning the subject incident. In addition, I am enclosing a copy of the police report of the same incident.

Basically, the D.S.R. is claiming that their bus was blown over the center line of Vernor Hwy. by a great gust of wind. Naturally, we are maintaining that the cause of the collision was the negligent observation and driving on the part of the bus driver, as well as his inability to cope with the weather conditions, rather than the wind.

Please inform me if you would be able to issue a comprehensive report, rebutting Mr. H.'s report, as well as testify to that effect in court, if necessary. If you have any questions, please call me.

Sincerely yours,

Attorney F.

MF/ml

Encl.

(Letter facsimile)

January 17, 1972

Mr. R. K.
Department of Street Railways
11200 Shoemaker
Detroit, Michigan 48213

Re: Wright - vs - D.S.R.
Maschke - vs - D.S.R.

Good Morning, Mr. K.:

This will serve to summarize my findings in the above captioned matter; and is addressed to your confidential attention, as a portion of your work product.

The conclusions obtained herein were derived of the facts in this matter, together with the physics of collision processes, without prejudice toward any of the involved parties; and represent my considered opinion and best engineering judgment, after extensive research and investigation.

The facts in this matter are contained within or obtained from the following:

1. The Detroit Police Department Accident Report (APB File No. D 1464, dated January 26, 1971);

2. The Local Climatological Data Report, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Metropolitan Airport, Detroit, Michigan, January 1971 (which contains the wind speed data for the date of this accident);

3. an examination of the D.S.R. bus in question (No. 2636) by me on January 13, 1972;

4. an examination of the accident scene by me on January 14, 1972.

The D.S.R. bus involved herein was headed west on W. Vernor, carrying the driver and two passengers, Raymond Bryant and James Wright, when a gust of wind supposedly forced the bus to its left, into the east bound side of W. Vernor, west of its intersection with Woodmere, and into the path of a 1967 Plymouth driven by Earl Maschke.

At the time of the accident it was daylight and snowing with icy pavement conditions on W. Vernor; the aforenoted weather report shows that, on that date, the peak wind speed was measured at some 50 miles per hour, with an average during the hours in question of some 32 miles per hour, with the wind direction out of the northwest, toward the southeast.

The D.S.R. bus in question is some 9 feet 11 inches in total height and some 39 feet 6 inches in overall length, with a wheelbase of some 23 feet. The weight on the front axle was found to be some 6100 pounds, and the weight on the rear axle was some 14,980 pounds. The center of gravity of this bus was thus determined to be some 16.35 feet aft of the front axle; or some 24.6 feet aft of the front of the bus; in non-technical terms, the center of gravity is the 'balance point' of the bus - there is as much weight to the rear of that point as there is to the front of that point.

The side presented area of the bus was determined to be some 392 square feet; and the center of pressure is some 19.75 feet aft of the front of the bus. The side presented area is that area over which the wind would exert its force; and that force would be centered at the center of pressure which, in this case, is the geometric center of the side of the bus.

A wind gust of 50 miles per hour in speed will exert a force of some 3920 pounds when it acts upon the side of this bus, normal to the side. In this case, since the bus was headed approximately west and the wind was out of the northwest, some of the frontal area of the bus would have been presented to the wind, increasing the above noted force of 3920 pounds; however, since it is not possible to accurately estimate the amount of presented frontal area which was effective, this factor will be ignored and it must be emphasized that, therefore, the following calculations will be somewhat conservative.

Since, in this bus, the center of pressure (the center of the force exerted by the wind) was foreward of the center of gravity, the wind gust would have forced the bus into a left turn situation since the gust acted upon the right side of the bus.

The coefficient of friction of an icy pavement can vary from 0.05 to 0.25. Consequently, since the front wheels of the bus carried some 6100 pounds, and since the bus was in motion at the time, the frictional forces which would have resisted lateral movement of the front tires would have been some 305 to 1525 pounds; or, some 915 $\pm$ 610 pounds.

In other words, since the frictional resistance at the front wheels of the bus was 915 $\pm$ 610 pounds, and since the force exerted on the right side of the bus was some 3920 pounds, and

since that wind force was exerted ahead of the center of gravity of the bus, it can be expected that the bus would have been forced to its left under the impact of a 50 mile per hour wind gust.

Accordingly, since the bus driver could not, most likely, have acted in time to prevent the bus from traveling the relatively short distance into the east bound lanes, and since the pavement was icy, it is my considered opinion and best engineering judgement that this accident was, most likely, caused by the combination of high gust winds and icy pavement; and, most likely, could not have been foreseen or prevented by the bus driver.

Further, since the average wind speeds were some 32 miles per hour, the average side forces exerted upon the bus would have been some 1607 pounds, or some 41% of the aforenoted gust wind forces; and on dry pavement, the resisting frictional forces would have been of the order of 4270 pounds - considerably higher than those forces obtained from the winds. Thus, it must be concluded that, most likely, the bus driver could have easily compensated for the average wind forces on dry pavement or, in fact, on wet pavement, and could have properly controlled the bus.

Based upon the facts which herein obtain, it must then be concluded that, again, this accident was caused by the high gust winds, combined with icy pavement; and was in no manner attributable to any action or lack of action on the part of the bus driver.

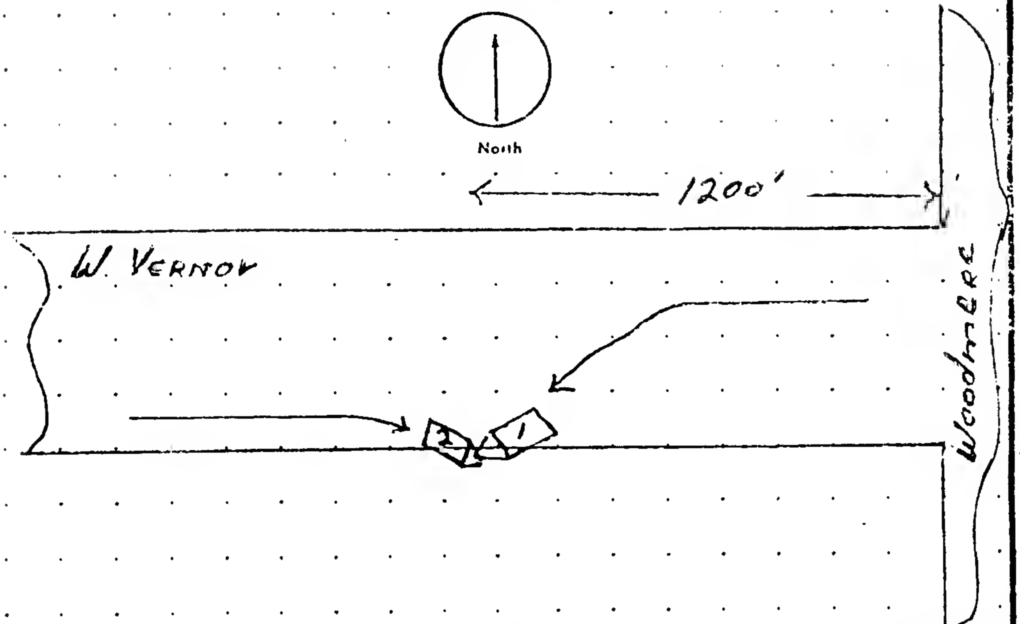
Very truly yours,

Mr. H.

ECL 218A

APB FILE NO D 1464

DRAW DIAGRAM OF ACCIDENT



INSTRUCTIONS:
(1) Use dotted lines as guides to draw heavy lines which will show outline of roadway at place of accident.
(2) Use dotted lines as guides to draw light dash between solid lines to show lanes of travel and divided roadways.
(3) Number each vehicle and draw them in proper lane.

POINT OF IMPACT
(Check one for each vehicle involved)

Vehicle 1. 2. 3.		Vehicle 1. 2. 3.	
X X	1. Front		5. Left side
	2. Right front		6. Rear
	3. Left front		7. Right rear
	4. Right side		8. Left rear

Describe briefly what happened including exact point of impact with fixed object:

#1 veh pushed across center line by gust of wind striking #2 veh. Very heavy winds + S.

	EMPLOYER'S NAME	ADDRESS (CITY)	PHONE NUMBER
DRIVER NO. 1	DSR	5600 Wabash	TY 5-3830
DRIVER NO. 2	Det. Fire Dept.	12th & LaBelle	
DRIVER NO. 3			

ADDITIONAL INFORMATION DSR Coach #2636 had only 2 passengers at time of accident

Assisted by Ptlr Terry Desjardais
Badge No 1444 Precinct or Bureau 4

APB Notified: Date 1-?-71 Time 12??
Officer LIVERNOIS Badge 299

PEDESTRIAN Was going ______ Direction (West, NE, etc.) On/Across ______ Street name
From ______ (NW Corner, South Side, Etc.) To ______ (SE Corner, North Side, Etc.)

1. Crossing at intersection—with signal
2. Same—against signal
3. Same—no signal
4. Same—diagonally
5. Crossing not at intersection—coming from behind parked cars
6. Same—not coming from behind parked cars
7. Coming from behind parked cars to enter vehicle
8. Playing in street
9. Getting on or off other vehicle
10. Standing in roadway
11. Playing in roadway
12. Working in roadway
13. Walking in roadway
14. Hitching on vehicle
15. Lying in roadway
16. Not in roadway (Explain in remarks)

WHAT DRIVERS WERE DOING
Vehicle (Check intent of each driver)
1. 2. 3.
1. Making right turn
2. Making left turn
3. Making U turn
X X 4. Going straight ahead
5. Slowing down or stopping
6. Overtaking
7. Leaving curb
8. Changing lanes
9. Backing
10. Stopped in traffic
11. Parked
(Check if applicable)
1. Skidding
2. Tire blew out
3. Avoiding vehicle, object or pedestrian
4. Emerging from alley or drive way

VIOLATIONS INDICATED (Check one or more for each vehicle)
Vehicle 1. 2. 3.
1. Exceeding lawful speed
2. Did not have right of way
3. On wrong side of road
4. Exceeding safe speed
5. Improper backing
6. Struck rear of vehicle
7. Improper passing
8. Cutting in
9. Failure to signal, Improper signal
10. Improper turn—wide right turn
11. Same—cut corner on left turn
12. Same—turned from wrong lane
13. Disregarded STOP sign, signal
14. Same—WARNING sign, sign
15. Disregarded Stop-&-Go light
16. Disregarded police officer
17. Improper starting from position
18. Improper parking
19. Disregarded YIELD RIGHT-OF-WAY Sign
20. Other improper action (expl
21. No improper driving indicat
X X Explain others:

CONDITION OF VEHICLE
Vehicle 1. 2. 3. (Check one or more)
X X 1. No defects
2. Improper lights
3. Defective brakes
4. Defective steering gear
5. Other defects
(Explain fully in remarks)

TRAFFIC CONTROL
Functioning / Not Functioning
1. Stop-&-Go light
2. STOP sign or signal
3. WARNING sign or signal
X 4. No control present
5. Officer or watchman
6. Railroad crossing gates
7. Railroad automatic si

CONDITION OF DRIVER AND PEDESTRIAN
1. 2. 3. Ped (Check one)
X X 1. Has not been drinking
2. Had been
(a) Drinking—Ability impaired
(b) Drinking—Ability not impaired
(c) Drinking—Not known whether impaired

1. 2. 3. Ped.
X X 1. Apparently normal
2. Physical handicap
Explain:
Alcohol Tests? Yes X No

ROAD TYPE (Check one or more for each driver)
DRIVER 1 2 3
1 driving lane
X X 2 driving lanes
3 driving lanes
4 or more lanes
Divided roadway (limited access)
Divided roadway (not ltd)
One way street

ROAD SURFACE CONDITION
1. Dry
2. Wet
X 3. Ice
4. Snow
5. Mud
6. Other (Spec.)

LOCALITY
1 Business
2 Industrial
3 Multi-Dwell
4 Single Dwell
5 School
X 6 Park
7. Open c...

WEATHER
1 Clear
2 Cloudy
3 Raining
X 4 Snowing
5 Fog
6

LIGHT CONDITIONS
X 1. Doylight
2 Dusk
3. Dawn
Darkness with
4 Artificial lights
5 No artificial lights

ROAD DEFECTS (Check one or more)
X 1. No defects
2. Holes or deep ruts
Loose material on surface
4. Defective shoulders
5 Other defects
6 Under construction or repair

ROAD CHARACTER X Straight X Level Curve or turn Grade Hillcrest

Lt Thomas C. ...

DPD ... For C of D-614 EL

July 1, 1971

Mr. G
Attorney at Law
55 Stout Street
Detroit, Michigan

RE: Maschke vs DSR
Your File 1986

Dear Mr. G.:

Reference your letter of June 24th, we have completed a study of weather conditions on January 26, 1971 at the location West Vernor west of Woodmere and have the following to report.

1) At the time of the accident at 11:05 a.m. January 26, 1971, a strong storm area was centered over the Georgian Bay area, which was moving slowly in a northeastward direction and influencing the Detroit weather.

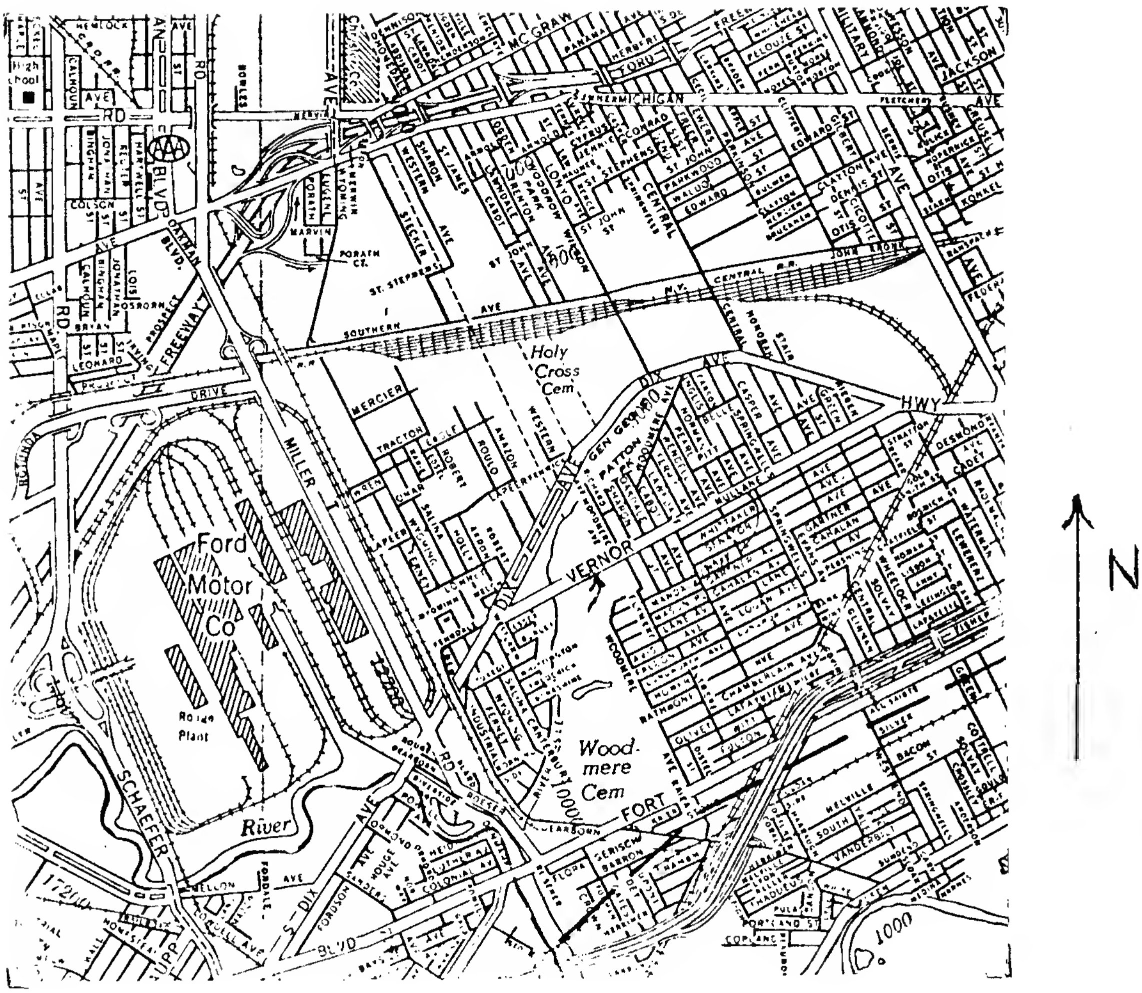
2) Weather conditions at the time of the accident at West Vernor west of Woodmere are estimated to be as follows:

   SKY : Overcast with light snow falling.
   WIND : Northwesterly 29 with gusts to 40 miles per hour.
   TEMPERATURE: 21 degrees (F).

3) It is estimated that approximately 1/2 inch of dry snow had fallen by the time of the accident. This was drifting . . . blown about by the wind.

Very truly yours,

H. A. B. - President



Accident Site

ECL 218B

25 July 1972

Dear Mr. F.:

Attached is an original with two copies of my comments relative to the accident involving a bus on 26 January 1971. If you have questions on this, please do not hesitate to ask them.

In going over a copy of the report written by Mr. H., it would be very interesting to determine how he arrived at his effective dynamic pressure of 10 lbs. per square foot. It would also be interesting to know why he has completely ignored any effect of friction at the rear wheels. These two questions are the kind of questions which should be raised in the event you take a deposition from him.

I trust my comments will supply your needs in this matter. I shall look forward to hearing further from you.

Sincerely yours,

C.O.S.

Enclosures

24 July 1972

Preliminary Report

Re: James Wright -vs- DSR
Earl Maschke -vs- DSR

The following has been prepared on the bases of a report by Mr. H., the police report of the incident, and a letter from the Weather Center. I have assumed that the dimensions and weight of the bus given by Mr. H. are correct. This information is summarized in Figure 1.

Air in motion against any object creates a dynamic pressure and an effective force (normally called "drag"). The dynamic pressure can be calculated from Eqn. 1 and the drag force from Eqn. 2. It is obvious that two of the critical factors are the wind speed and the drag coefficient. The drag coefficient is dependent upon the geometry, edge conditions, etc, of the body upon which the wind impinges.

<u>Dynamic pressure</u>

$$P = 0.5 \quad qV^2 \qquad (\text{lb/ft}^2) \qquad \text{Eqn. 1}$$

where q = mass density

0.00238 lb sec^2/ft^4

V = speed in ft/ sec

or

$$P \simeq \frac{V^2}{392}$$ where V = speed in mph

<u>Effective force</u>

$$D = C_d \, P \, S \qquad (\text{lb}) \qquad \text{Eqn. 2}$$

where C_d = drag coefficient

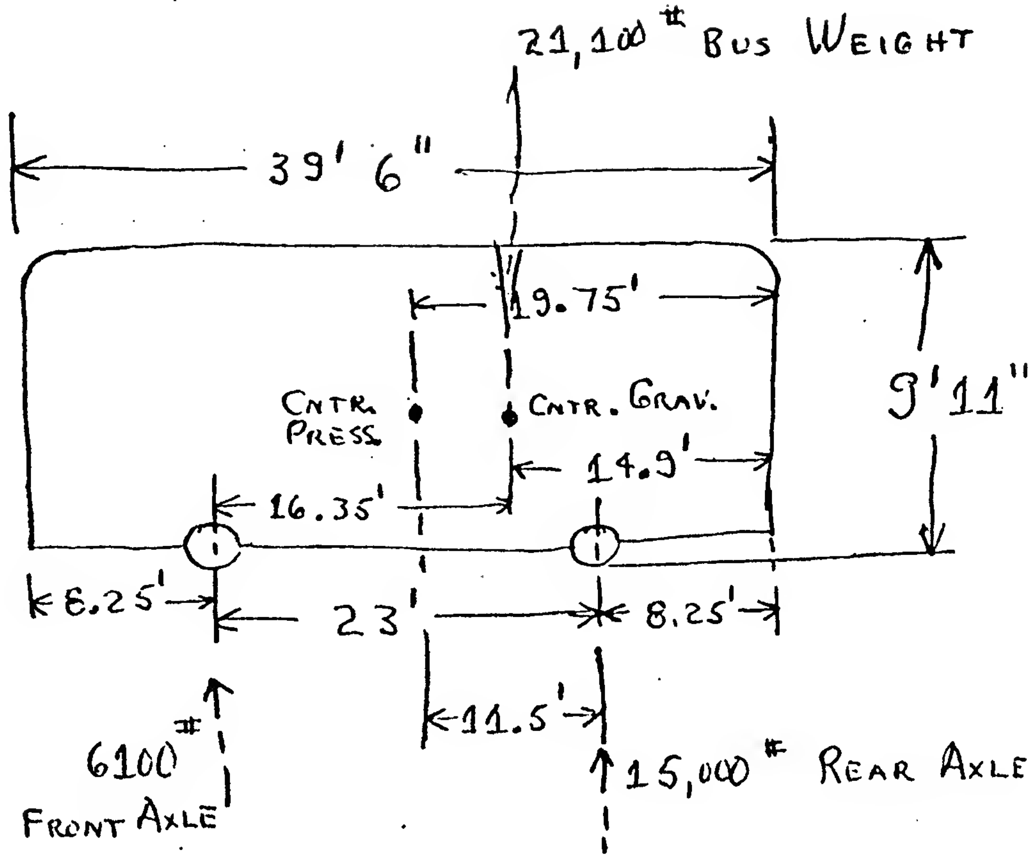
P = dynamic pressure (lb/ft^2)

S = projected area (ft^2)

(9'11" x 39'6" = 392 ft^2)

James Wright -vs- DSR
Earl Maschke -vs- DSR

24 July 1972



Schematic Sideview of Bus

Figure 1.

The data submitted to me indicate an average wind speed of 32 mph, a maximum of 40 mph (from Brady Weather Center in Detroit) at about the time of the accident, and a maximum of 50 mph (from Mr. H.). The best data source (a widely used reference) I can find gives a drag coefficient for a "box" bus with rounded corners of 0.46. The automobile industry normally uses a drag coefficient of 0.70 for automobiles. Mr. H. used an effective drag coefficient of 1.00. The dynamic pressure and the effective drag force have been calculated and are shown in Table 1 for the various combinations of wind speed and drag coefficient. It might be noted that an area of 392 sq. ft. was used, although the actual side area of the bus would be somewhat less.

It has been noted that the wind was out of the northwest at the time in question and the bus was proceeding westerly on Vernor in the vicinity of General George S. Patton Park. At that point, Vernor bears about 28° south of true west so that the wind was actualy striking the side of the bus at an angle of perhaps 15° to 20° from a direction perpendicular to the bus. As a result there is little effect of this angular difference and the calculations have been made as if the wind were perpendicular to the side of the bus. Any effect on the front of the bus has thus been ignored.

TABLE 1

Dynamic Pressure & Drag Force

V mph	P lb/ft^2	D, lb		
		$C_d = 0.46$	$C_d = 0.70$	$C_d = 1.00$
32	2.6	470	710	1020
40	4.1	740	1120	1600
50	6.4	1150	1730	2500

Figure 2 shows a schematic top view of the bus with the effective location of the drag force shown. The tires on the roadway will develop a resisting frictional force opposing motion or impending motion. If no force is applied, no frictional force is developed. The maximum frictional force which can be developed is limited by the coefficient of friction (the ratio of the resisting force to the force normal to the plane of motion, i.e., the weight). For rubber on ice, the coefficient of friction can vary from 0.05 to 0.20 or 0.25. If a coefficient of friction of 0.05 is used, then the maximum frictional force which the front weeels can exert is 305 lb. while the rear wheels can exert a maximum frictional force of 750 lb.

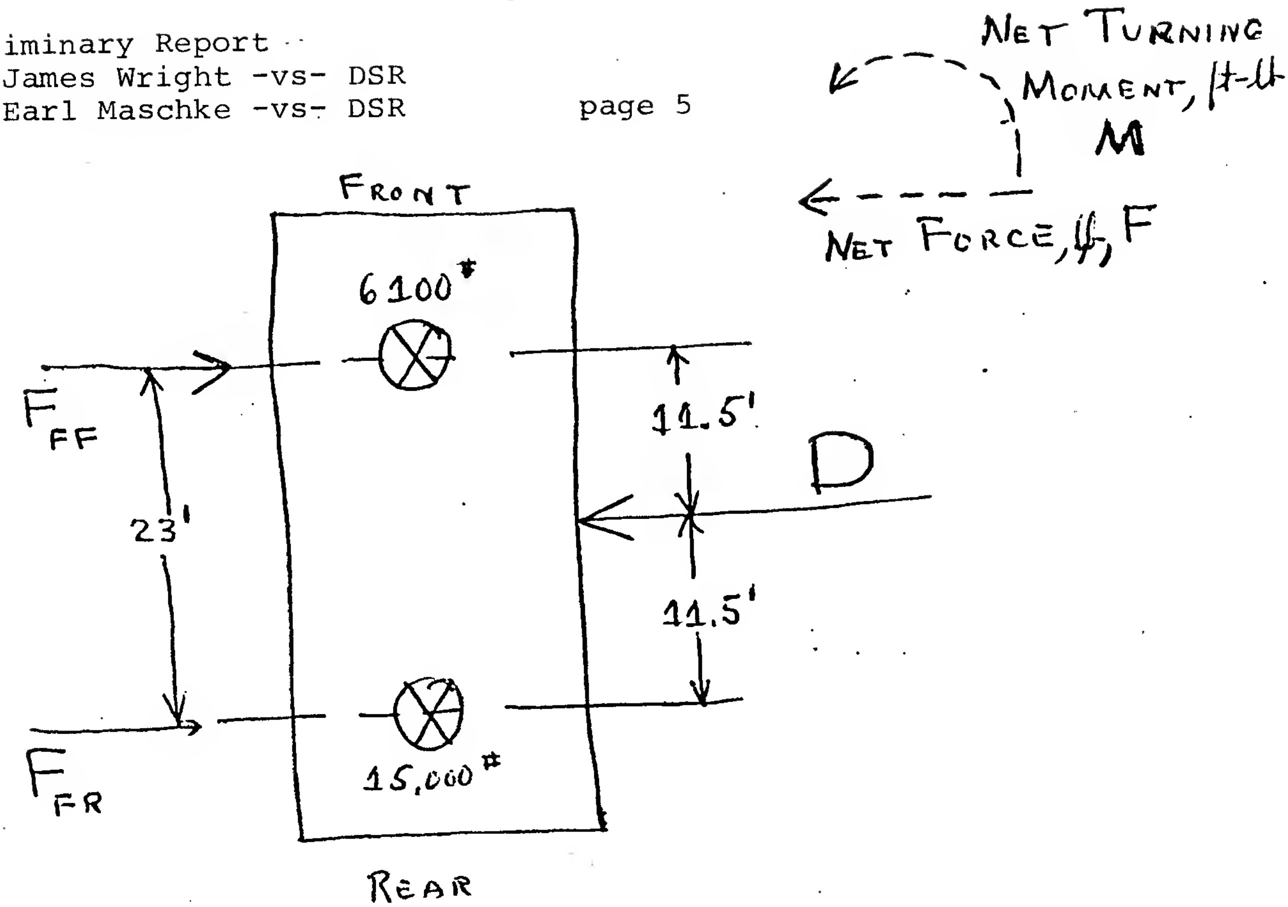
If the drag force exceeds the sum of the two frictional forces, there will be a net force acting as shown at the top right hand corner of Fig. 2. A net turning moment can also be exerted as shown in the top right hand corner of Fig. 2. If there is a net sidewise force, the bus will tend to move (slide) to the left. If there is a net turning moment, the bus will tend to rotate and thus turn to the left.

The net force and net turning moment have been calculated for the same conditions used in Table 1 and are given in Table 2.

TABLE 2

Net Force & Turning Moment

V	$C_d = 0.46$		$C_d = 0.70$		$C_d = 1.00$	
mph	F_{lb}	$\overset{M}{\text{ft-lb}}$	F_{lb}	$\overset{M}{\text{ft-lb}}$	F_{lb}	$\overset{M}{\text{ft-lb}}$
32	0	0	0	1160	0	4700
40	0	1500	65	5900	545	11400
50	95	6200	675	12900	1445	21900



F_{FF} = FRICTIONAL FORCE, FRONT

F_{FR} = FRICTIONAL FORCE, REAR

SCHEMATIC TOP VIEW OF BUS

FIGURE 2.

It is my opinion that use of a wind speed of 40 mph and a drag coefficient of 0.46 is appropriate. When used in conjunction with the smallest probable coefficient of friction, the net sidewise force is zero and there is a net turning moment of 1500 ft-lb. This would tend to turn the bus to the left but with the inertia of the bus, this would represent a very slow turning. If a wind speed of 50 mph is used with the same coeffieient of friction, there is a net sidewise force of 95 lb and a net turning moment of 6200 ft-lb. These would tend to slide the bus to the left and cause it to turn to the left. While this turning would be somewhat more rapid than with the lower wind speed, this would still be a slow turning. Even if one were to adopt the drag coefficient of 0.70 used for automobiles, with a wind speed of 50 mph, there would be a lateral acceleration of about 1 ft/sec^2 (about 1/30 of the acceleration in a freely falling object) and a rotational acceleration of less than 8°/sec^2.

It should be noted that any lateral acceleration and rotational acceleration means that sidewise movement or turning would continue (and increase) only if the drag force from the wind were continued. One would expect a skilled driver to apply brakes and compensate for this by attempting to turn his vehicle. It should further be noted that the wind was gusty which should put a skilled driver on a "constant" alert. Another aspect of the gusts is that the lateral and rotational accelerations would only be applied while the gust was blowing. The fact that gust speeds of 50 to 60 mph were recorded during the afternoon of the day in question is of no consequence since the accident occurred in the morning.

There is no question in my mind that gusts of about average (or higher) wind speed would tend to turn the bus to the left. The greater the wind speed, the greater will be the turning tendency. It is difficult to visualize that a skilled driver could not properly compensate for this and maintain control with wind gust speeds of up to 50 mph, especially if traveling to the right on a street with 2 westbound and 2 eastbound traffic lanes.

Conclusion

Using the indicated maximum wind speed (at the time of the accident) of 40 mph; the dimensions given for the bus; formulae and coefficients of drag and friction from standard recognized sources; and the minimum expected coefficient of friction (thus assuming the worst possible condition), there would be no net sidewise force on the bus and a net turning moment of only 1500 ft-lb. This would tend to turn the bus

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to the left but at a very slow rate. If one assumed higher wind gust speed and a higher drag coefficient, then there would be some sidewise force and a greater net turning moment which would slide the bus to the left and cause it to turn left at a greater rate. I do not believe, however, that the net force and turning moment on the bus (under the conditions reported) were sufficient, by themselves, to cause it to depart as far from its course as has been reported.

Reference: "Fluid-Dynamic Drag", S. F. Hoerner, Library of Congress Card No. 57-13009

INSTRUCTOR'S NOTE

Part A

It is suggested that this part be given to the students and let them see if they can respond appropriately to F.'s letter.

Part B

Now that the students have the rebuttal to H.'s report, they can proceed to work over both reports and criticize, constructively or otherwise.

It might be noted that Atty. F. decided not to use a technical witness if the other side (DSR) did not. As a consequence, only the individuals, DSR, and attorneys appeared in court. The claim of the plaintiffs, Wright and Maschke, was not upheld.